

# THE CALCULATION OF NEUTRON CAPTURE GAMMA-RAY YIELDS FOR SPACE SHIELDING APPLICATIONS

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In general, the application of nuclear models to the calculation of neutron capture and inelastic scattering gamma yields is undertaken with the following purposes in mind:

1. to calculate capture gamma-ray spectra where not even partial spectrum measurements are available. In such cases a data vacuum is filled with the understanding that if and when reliable measurements appear which seriously conflict with the calculation, the gamma yield data will be updated as required.
2. to fill in gaps in measured capture gamma-ray spectra, generally in the continuum region. In such cases available experimental data are used to aid in the definition of model parameters.
3. as a part of data analysis procedures for nominally complete capture gamma measurements such as those done recently at GGA for W and U-238. This combining of advanced measurement and theoretical techniques seems to represent the optimum approach to the data acquisition problem.

The gamma-ray cascade model, DUCAL<sup>(1)</sup>, developed as part of the Oak Ridge Program to generate capture and inelastic scattering gamma yields describes the cascade process in terms of parameters which either a) embody statistical assumptions regarding electric and magnetic multipole transition strengths, level densities and spin and parity distributions, or b) are fixed by experiment such as measured energies, spin and parity values, and transition probabilities for low lying states. Calculation of the latter with an appropriate nuclear model are attempted only for energies/mass regions for which either the model has been shown to apply or its predictions are judged to be closer to the truth than statistical assumptions.

With the foregoing limitations in mind, the viability of calculated yields may be considered in

the light of the properties of the nuclei involved, experimental information available for the definition of model parameters, and the use for which the yields are intended. In particular, the DUCAL code has been used exclusively to generate gamma yields for neutron gamma-ray production cross sections to be input to transport codes for the calculation of integrated gamma dose at some point in a shield. As discussed in an earlier paper,<sup>(2)</sup> inaccuracies in calculated yields which lead to discrepancies in the calculated differential gamma flux do not necessarily result in significant errors in the calculated integrated dose. Errors in gamma group fluxes which are substantially compensating over several neighboring groups tend to be cancelled out in the process of folding the fluxes with the flux to the dose conversion ratio. A major consideration in the calculation of integrated dose is the conservation of gamma energy in the decay process. This the cascade model does as a matter of course.<sup>(1)</sup>

The fundamental nuclear properties are of particular significance where one attempts to calculate neutron energy dependent capture gamma yields for an element. The number of naturally occurring isotopes, their level structure, and the relative magnitudes of the binding energies of isotopes formed by neutron capture are extremely important. Changes in the capture spectrum with neutron energy associated with shifts in the relative magnitudes of capture cross sections of isotopes having different binding energies and level schemes, as in W,<sup>(3)</sup> can often be reasonably accounted for since a) the gamma cascade model conserves energy, and b) measured low lying level structure is frequently available for input to the calculation. In addition, the neutron energy dependence of the capture spectrum associated with changes in the capture state spin and parity resulting in the accessibility of different sets of low lying states to E1 and M1 transitions can be accounted for to within the approximation of constant M1, E1 and E2 primary trans-

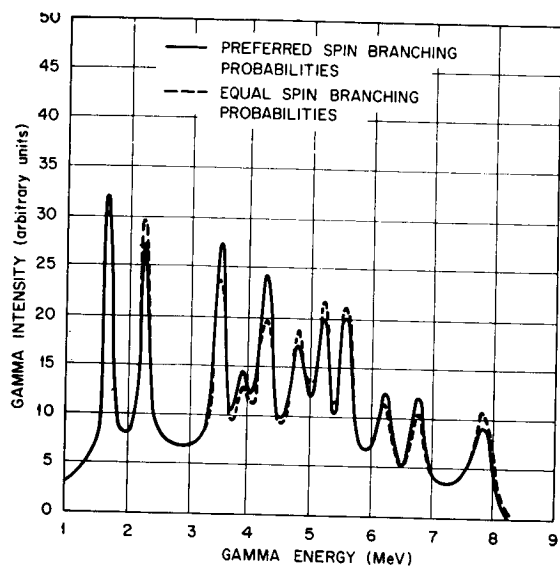


Figure 1 Comparison between fitted (—) and equal (---) dipole transition strength calculations of the capture gamma yield for the 35 keV  $^{27}\text{Al}$  resonance.

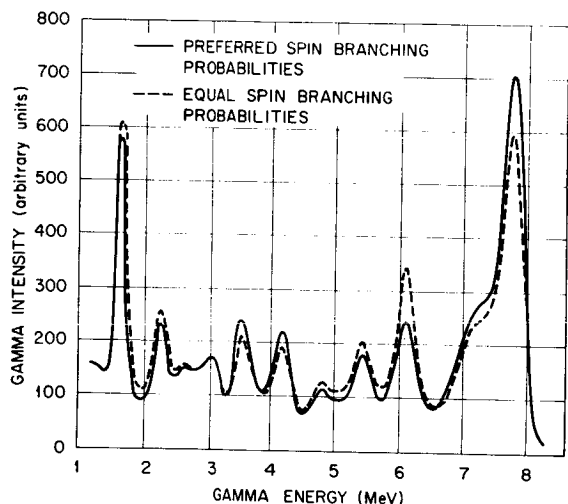


Figure 2 Comparison between fitted (—) and equal (---) dipole transition strength calculations of the capture gamma yield for the 120 keV  $^{27}\text{Al}$  resonance.

ition probabilities. An example is seen in the calculation of capture gamma spectra for the 35 keV  $3+$  and 120 keV  $2^-$  resonances in  $^{27}\text{Al}$  shown in figures [1] and [2]. Differences in the capture spectra represented by the dashed curves are attributable solely to the nuclear selection rules operating in conjunction with fixed M1, E1 and E2 transition strengths. In contrast, changes in the capture spectrum with capture state which depend upon more subtle wave function characteristics clearly cannot be approximated by a model.

A number of nuclear models have been implemented to aid in estimating low energy level structure and gamma decay schemes used to define corresponding parameters in the DUCAL code. These include a "unified" model which combines the Nilsson treatment of an odd particle in a deformed, rotating potential well with the Faessler-Sheline treatment of collective vibrational modes of excitation<sup>(4)</sup>, and a model for odd-odd nuclei which employs products of single particle Nilsson wave functions as basis functions and the Gallagher-Moskowsky coupling rules for the angular momenta of the odd nucleons.<sup>(5)</sup> In addition, a parameterization scheme to extend the applicability of the of the foregoing odd-A model has been investigated<sup>(6)</sup>. This involved an attempt to correlate values of a) a spin-dependent inverse moment of inertia corresponding to a best fit between measured and calculated level energies, and b) a deformation parameter to which the E2/M1 ratio is sensitive.

The foregoing nuclear models have been used to generate neutron energy dependent capture gamma-ray yields for tungsten, tantalum, U-238 and iron<sup>(3,7)</sup>. In each case the calculated yields have been tested against integral capture gamma yield measurements performed at the Oak Ridge Tower Shield Facility.

#### REFERENCES

1. Nucl. Sci. Eng., **32**, 62 (1968).
2. Transactions of the Conference on Neutron Cross Sections and Technology, NBS Special Publication 299, Vol 1, 53 March (1968).
3. Trans. Am. Nuc. Soc., **12**, 386 (1969).
4. Nucl. Sci. Eng., **36**, 189 (1969).
5. Nucl. Sci. Eng., **41**, 193 (1970).
6. Nucl. Sci. Eng., **39**, 379 (1970).
7. Trans. Am. Nuc. Soc., **13**, 866 (1970).